Universitätsspital Zürich
Klinik für Mund-, Kiefer- und Gesichtschirurgie
Direktor: Prof. Dr. med. Dr. med. dent. Martin Rücker

---

Arbeit unter Leitung von Prof. Dr. med. univ. Dr. med. dent. Joachim A. Obwegeser

# Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery

**INAUGURAL-DISSERTATION**
zur Erlangung der Doktorwürde der Zahnmedizin
der Medizinischen Fakultät
der Universität Zürich

vorgelegt von
Ariella Denise Dietrich
von Dägerlen ZH

Genehmigt auf Antrag von Prof. em Dr. med. Dr. med. dent. K.W. Grätz
Zürich 2014

## Publikationshinweis

*Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery*


| | |
|---|---|
| Publiziert am: | 10. April 2014 |
| Journal: | Journal of Cranio-Maxillo-Facial Surgery |

Journal of Cranio-Maxillo-Facial Surgery xxx (2014) 1–9

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

# Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery

John Patrik Matthias Burkhard [a,*,1], Ariella Denise Dietrich [a,1], Christine Jacobsen [a], Malgorzota Roos [b], Heinz-Theo Lübbers [a], Joachim Anton Obwegeser [a]

[a] Department of Cranio-Maxillofacial and Oral Surgery, University Hospital Zurich, Switzerland
[b] Biostatistics Unit, Institute of Social and Preventive Medicine, University of Zurich, Switzerland

ARTICLE INFO

*Article history:*
Paper received 27 January 2014
Accepted 10 April 2014

*Keywords:*
Orthognathic surgery
Posterior airway
CBCT
Cephalometry
Imaging software

ABSTRACT

*Purpose:* This study aimed to compare the reliability of three different imaging software programs for measuring the PAS and concurrently to investigate the morphological changes in oropharyngeal structures in mandibular prognathic patients before and after orthognathic surgery by using 2D and 3D analyzing technique.
*Material and methods:* The study consists of 11 randomly chosen patients (8 females and 3 males) who underwent maxillomandibular treatment for correction of Class III anteroposterior mandibular prognathism at the University Hospital in Zurich. A set of standardized LCR and CBCT-scans were obtained from each subject preoperatively (T0), 3 months after surgery (T1) and 3 months to 2 years postoperatively (T2). Morphological changes in the posterior airway space (PAS) were evaluated longitudinally by two different observers with three different imaging software programs (OsiriX® 64-bit, Switzerland; Mimics®, Belgium; BrainLab®, Germany) and manually by analyzing cephalometric X-rays.
*Results:* A significant increase in the upper airway dimensions before and after surgery occurred in all measured cases. All other cephalometric distances showed no statistically significant alterations. Measuring the volume of the PAS showed no significant changes in all cases. All three software programs showed similar outputs in both cephalometric analysis and 3D measuring technique.
*Conclusion:* A 3D design of the posterior airway seems to be far more reliable and precise phrasing of a statement of postoperative gradients than conventional radiography and is additionally higher compared to the corresponding manual method. In case of Class III mandibular prognathism treatment with bilateral split osteotomy of the mandible and simultaneous maxillary advancement, the negative effects of PAS volume decrease may be reduced and might prevent a developing OSAS.


## 1. Introduction

Orthognathic surgery is primarily conducted for treatment of congenital or acquired craniofacial deformities and aims to restore proper dental occlusion and facial harmony (Popat et al., 2012; Rustemeyer and Gregersen, 2012). It comprises several surgical techniques that allow to reshape the entire mid-face, mandible and dentoalveolar segments through the modification of the facial bones (Lye, 2008). Surgical alterations in the position of the bony facial skeleton imply secondary changes of the relationship between muscles, soft and hard tissues (Turnbull and Battagel, 2000). These movements have influence on profile and shape of the entire face as well as in alterations of the oral and nasal cavity and the pharyngeal airway dimensions (Lye, 2008; Hernandez-Alfaro et al., 2011).

Interest in the shape and dimensions of the upper airway has increased steadily during the past decades mainly due to the relationship between upper airway configuration and obstructive sleep apnoea (OSA). Together with craniofacial morphology, the posterior airway space (PAS) and respiratory function are highly relevant to the orthodontic specialty (Guijarro-Martinez and Swennen, 2011). Based on lateral cephalometric analysis, many studies have already

* Corresponding author.
*E-mail address:* s0471919@me.com (J.P.M. Burkhard).
[1] Authors equally contributed.

http://dx.doi.org/10.1016/j.jcms.2014.04.005

dealt with the effects of orthognathic treatment on the facial skeleton and the upper pharyngeal airway (Mehra et al., 2001; Eggensperger et al., 2005; Goncalves et al., 2006; Muto et al., 2006). Due to soft tissue alterations, several studies have shown that mandibular setback surgery may cause a downward movement of the hyoid bone, the tongue base and consequently narrows the PAS (Eggensperger et al., 2005; Kawakami et al., 2005; Marsan et al., 2010; Hong et al., 2011). This pharyngeal narrowing represents particular interest because of its possible contribute to further development of OSA and its relationship to maintaining normal respiration (Tiner, 1996; Chen et al., 2007; Degerliyurt et al., 2008; Jakobsone et al., 2010). As a result of an untreated OSAS, certain chronic health problems may occur such as cardiovascular diseases which may manifest in arterial and pulmonary hypertension or cardiac arrhythmias up to sudden cardiac death and insulin resistance (Grimm and Becker, 2006).

In contrast, to achieve an enlargement of the posterior airway dimensions, maxillomandibular advancement surgery has been proven to be very efficacious for elimination of OSAS. It stretches the upper airway muscles and tendons (velopharyngeal and suprahyoidal musculature) by advancement of their osseous origin (Hochban et al., 1997; Mehra et al., 2001; Prinsell, 2002; Eggensperger et al., 2005; Fairburn et al., 2007). After surgery, the position of the hyoid bone becomes more anterior with additional alterations in tongue position and consequent widening of the pharyngeal airway dimensions postoperatively (Riley et al., 1990; Turnbull and Battagel, 2000; Li et al., 2001). However Schendel and Epker affirmed only a temporary stability. After a certain period, the hyoid bone tends to return to its original position. This relapse may be caused by adjustments of the tendons and muscles to their location of attachment to the bones, as well as changes in the tendon–bone interface (Schendel and Epker, 1980). Mandibular advancement alone may not achieve a stable increase of the pharyngeal airway dimension over a long-term period (Eggensperger et al., 2005).

During the past few years, three-dimensional imaging procedures of the PAS have become more important for the ability to predict the effects of orthognathic surgery treatment and to understand and diagnose obstructed sleep disordered breathing (Mah et al., 2003; Schendel and Hatcher, 2010).

Traditionally, the PAS has been evaluated using lateral cephalometric radiographs (LCR), which allows precise measurements of the sagittal plane and has the advantages of a low cost and minimal exposure radiation (Li et al., 1999; Muto et al., 2006, 2008). But this method results in the superimposition of all bilateral structures of the craniofacial complex and only provides a two-dimensional anteroposterior linear measurement (Muto et al., 2008). Besides that, the axial plane cannot be examined (Abramson et al., 2010).

In the past few years, airway evaluation became more reliable with the technological advance of three-dimensional recording techniques such as computed tomography (CT), magnetic resonance imaging (MRI) or recently, cone beam-computed tomography (CBCT). CBCT is distinguished by their compact size, relatively low radiation dosage and high image accuracy in identifying the boundaries of soft tissues and empty spaces (Aboudara et al., 2009; Hernandez-Alfaro et al., 2011). The CBCT imaging technique became very popular in different domains, not only in examining the pharyngeal airway (Guldner et al., 2011). The advantage of three-dimensional imaging is shown in spatial resolution, rotatable images in the three axes and selective visualization of certain anatomical structures (Angelopoulos, 2008). To assess anatomical structures, as the upper airway, several software programs designed to manage and analyze digital imaging communications in medicine (DICOM) files are used (Sutthiprapaporn et al., 2008). Many of these have integrated tools to segment and measure the airway linear or volumetrically. A systematic review of the literature attested 18 imaging software programs for viewing, measuring, segmenting, and complete analysis of the upper airway in CBCT. However, validation studies with a clear study design were performed for 4 software programs. The systematic review suggested that studies assessing the accuracy and reliability of current and new software programs must be conducted before these imaging software programs can be implemented for airway analysis (Guijarro-Martinez and Swennen, 2011).

Evaluation of the shape, size and volume of the posterior airway space starts with segmentation. Segmentation means to define different related anatomical structures such as soft tissues, bones or vessels and calculate them into their three-dimensional surface models. Segmentation is used to simply express a specific element and remove all the surrounding structures of noninterest for a better visualization and analysis. Corresponding to the pharyngeal airway dimension, segmentation of the PAS can be evaluated manually or semiautomatic. Fully automated computer-aided segmentation has still many restrictions left. Mostly, the reasons are to be found in the high heterogeneity of the image data (such as noise-induced error, artefacts, etc.). Furthermore, the selection of an initial threshold and placement of initial seed regions depends in each case on the examiner (Riley et al., 1987). Even during the radiographic scanning procedure patients movement may produce motion related artefacts, which can have some influence on the segmentation accuracy (Celenk et al., 2010).

The basis of every segmentation approach is to set a certain image threshold correspondent to the tissue of interest. Every voxel with grey levels inside that interval will then be rendered to a three-dimensional model. A single threshold value is certainly more reproducible than the use of dynamic threshold but implicates more errors, especially in volume analysis (Lenza et al., 2010).

The manual approach of segmentation is performed slice-by-slice, where every region of interest has to be selected individually. This method is inefficient and inappropriate for daily clinical application because of long procedures. Far better, faster and more precisely appears the semiautomatic segmentation. By calculating the difference in density values of the structures the computer is able to automatically differentiate the air and the surrounding soft tissues. Usually an interactive placement of initial seed region in the axial, coronal and sagittal slice helps to determine the region of interest (Grauer et al., 2009).

The purpose of this study was to compare the reliability of 3 imaging software programs for measuring the PAS and concurrently to investigate the morphological changes in oropharyngeal structures in mandibular prognathic patients before and after orthognathic surgery by using CBCT-scans and traditional LCR. Up to now, only a few studies have been trying to compare these two different measurement techniques together to verify the validity of LCR in analyzing the PAS before and after surgery with examining simultaneously the reliability of the used measurement methods.

## 2. Materials and methods

### 2.1. Study population

In this retrospective study, 11 patients (8 women, 3 men) underwent maxillomandibular treatment for correction of Class III anteroposterior mandibular prognathism from 2009 to 2011 at the Department of Cranio-Maxillofacial and Oral Surgery at the University Hospital Zurich. The patients were randomly selected from the database of the Department. The median age of the patients at surgery was 26 years, with a range from 19 to 44 years.

The surgical treatment in all cases consisted of bilateral sagittal split ramus osteotomy and Le Fort I osteotomy with fixed rigidly titanium miniplates. Exclusion criteria were previous orthognathic treatment and cleft lip, cleft palate or alveolus. All specimens were primarily obtained for medical purposes, with the informed consent of the patients. The study design fulfils the guidelines of the Declaration of Helsinki regarding ethical principles for medical research involving human subjects.

### 2.2. Imaging procedure

All 11 patients received standardized pre- and postoperative LCR and CBCT-scans. The LCR was taken in natural head posture with the ESOSTAT-Tele 2000 (E. Schweizer AG, Zürich) to assess skeletal characteristics and pharyngeal airway dimensions before surgery (T0), from 3 months postoperatively (T1) and from 3 to 19 months after surgical treatment (T2). CBCT-scans were performed with the KaVo 3D Exam digital volume tomography (KaVo Dental GmbH, Biberach, Germany). Every CBCT-scan was taken while patients were sitting in an upright position, breathing quietly, the tongue in a relaxed position and with the clinical Frankfort horizontal plane parallel to the floor.

### 2.3. LCR assessment

For linear assessment, every printed LCR was processed by hand using scale and reference models as control. Each volumetric data set was traced in the mid-sagittal CBCT-slide mapping the centre of the sella analyzed with two different software programs, OsiriX® and Mimics® (OsiriX® 64-bit extension, Switzerland; Mimics®, Materialise HQ, Leuven, Belgium). OsiriX® was running on an Apple® MacBook running MacOS 10.8 (late 2008) and Mimics® and BrainLab® software were operated on a Hewlett Packard® Personal Computer running Windows® XP (SP2). All cephalometric analysis were traced by two different examiners. The following cephalometric landmarks were used for analysis (Figs. 1 and 2):

The length of the skull base measured from the centre of the bony crypt of the sella turcica (S) and the most anterior point of the naso-frontal suture (N) was used as a reference structure. A line drawn perpendicular to S represented the vertical reference line (VR) to measure all cephalometric distances vertical to this line. A line connecting the skull base (C) and the posterior nasal spine (PNS) defined the superior border of the PAS. The posterior pharyngeal wall outlined the posterior border and the anterior border was determined by the posterior root of the tongue, the soft palate and the uvula. The anteroposterior pharyngeal dimension was measured at three different levels vertical to VR.

The upper pharyngeal anteroposterior dimension (UPW) was defined by connecting the point of the bony posterior nasal spine (PNS) to the posterior pharyngeal wall defined. The middle pharyngeal dimension (MPW) was measured from the posterior aspect of the tongue (U) closest to the posterior pharyngeal wall and the lower pharyngeal dimension (LPW) as a line connecting the base of the epiglottic vallecula (E) to the posterior pharyngeal wall. $AP_{min}$ was defined as the narrowest anteroposterior dimension. For determination of the hyoid bone and the mandible position, two parallel lines were drawn from the posterior pharyngeal wall (PPW1 and PPW2) to the anterior upper part of the hyoid bone (H) and the most anterior point of the bony chin (Pg) as shown in Fig. 1.

### 2.4. CBCT assessment

Each CBCT-scan was independently traced and evaluated by two different observers. Therefore, three software applications OsiriX®, Mimics® and BrainLab® (OsiriX® 64-bit, Switzerland; Mimics®, Materialise HQ, Leuven, Belgium; BrainLab®, BrainLab AG,

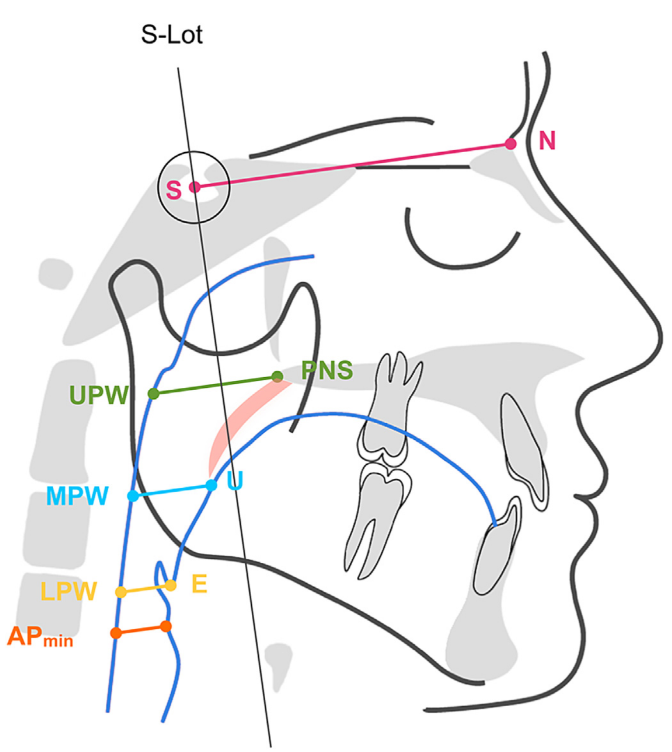


**Fig. 1.** Lateral cephalometric landmarks, lines and variables. Points: 1) S: sella turcica, 2) N: nasion, 3) PNS: posterior nasal spine, 4) UPW: upper pharyngeal wall, 5) U: Uvula, 6) MPW: middle pharyngeal wall, 7) E: epiglottic vallecula, 8) LPW: lower pharyngeal wall, 9) $AP_{min}$: smallest A-P distance.

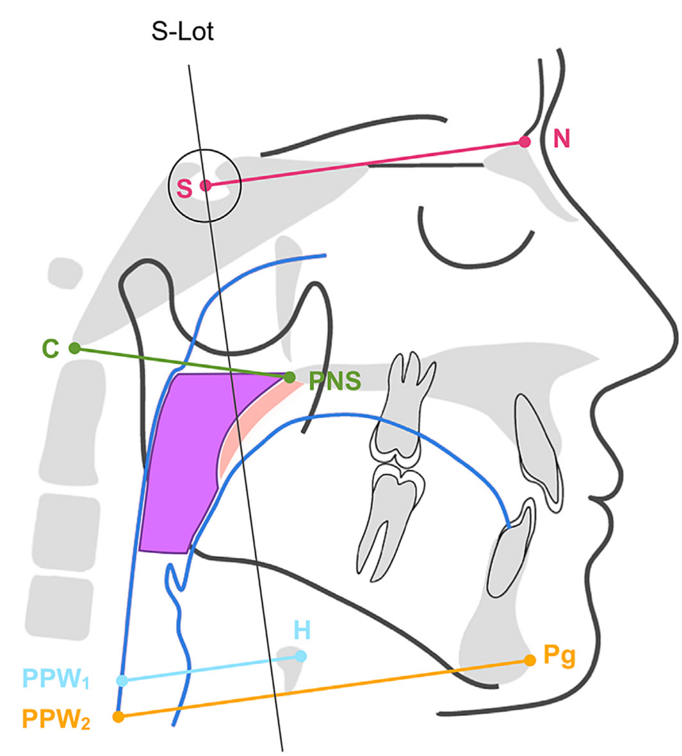


**Fig. 2.** Lateral cephalometric landmarks, lines and variables. Points: 1) S: sella turcica, 2) N: nasion, 3) PNS: posterior nasal spine, 4) C: posterior border of Clivus, 5) H: hyoid bone, 6) $PPW_1$ and $PPW_2$: posterior pharyngeal wall, 7) Pg: Pogonion, 8) FH: Frankfort horizontal, 9) Violet coloured area represents the posterior airway space.

Please cite this article in press as: Burkhard JPM, et al., Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery, Journal of Cranio-Maxillo-Facial Surgery (2014), http://dx.doi.org/10.1016/j.jcms.2014.04.005

Feldkirchen, Germany) were used for the three-dimensional volume rendering.

To build three-dimensional models of the PAS, all anonymous CBCT-data sets were loaded into each software program. To calculate the airway space in the CBCT-scans, threshold segmentation was used. Although it is mainly an automatic procedure, there were two interactive steps to start the segmentation. First, an initial threshold referencing free air was selected. Because the free air space is pictured in CBCT-scans more hypodense than the surrounding soft tissue, a distinctive high-contrast border was used for threshold segmentation. The threshold limits were manually modified to an appropriate range to capture all spaces filled by air within the volume. A further ROI (region-of-interest) mask editing tool function was utilized to determine the relevant anatomical structures. Some remaining artefacts or uninterested structures like nasal cavity, maxillary sinuses or oral cavity were removed directly by hand before calculating the final three-dimensional model. The volume was measured as seen in Fig. 2.

### 2.5. Statistical analysis

Data were coded in Microsoft® Excel® (version 2011 for Macintosh) and statistically evaluated by using the Statistical Package for Social Sciences for Macintosh (SPSS® version 20, Chicago). Intra-observer reproducibility was assessed by calculating systematic error using the Dahlberg formula. The systematic error was up to standard ($p < 0.05$).

The results of comparing the software programs regarding 2D and 3D analysis were evaluated with the non-parametric Wilcoxon-test. Ancillary, for the 3D data analysis the diameter and the volume were used. In this case, the diameter is required to demonstrate the normal distribution. Two ways interactions were used (observer/patient; observer/program; program/time; time/patient; time/observer; program/patient). A post performed analysis was made using ANOVA for repeated measurements, with the corresponding post-hoc tests with Bonferroni technique (with factors: operator, time, program, all three as fix factors, patient and random factor). A confidence interval of 95% was chosen. The reliability was calculated by using the diameter and the volume for the observer and for the programs.

For statistical analysis of pre- and postoperative measurements initially descriptive statistics such as mean and standard deviation were processed. The assumption of normality of the data was tested by Kolmogorov–Smirnov and Shapiro–Wilk tests. As the assumption of normality of the data has been rejected, the paired non-parametric Wilcoxon-test with Bonferroni corrected $p$-value ($p = 0.05/3 = 0.016$) was used.

## 3. Results

The mean values of the cephalometric analysis and the volume measurements are shown in Table 1. The analysis of the software programs showed at T0 a significant difference ($p < 0.05$) between preoperative measured values of LCR compared to the values from Mimics® and OsiriX® for the distance PNS-C, as well for the lengths PNS-UPW measured in OsiriX®. The same results were found at T1, wherein addition significant differences were found for PNS-UPW between LCR to Mimics®. At T0 Mimics® showed significant difference to OsiriX® for the distance Pg-$PPW_2$, which was also observed at T1 for E-LPW and at T2 for PNS-UPW. Generally, the results addicted no statistically proved differences for a single measurement of the airway lengths, especially in the lower part of the pharynx (Table 1). Patients had big volume variances by every measurement, what is labelled as the random factor. The Box-plot charts (volume and diameter calculation) give a clear view over the measurement techniques at different times within the two observers. It is clearly showed that the intra-observer reproducibility is comparable. The software programs show all the same development and the volume values have similar ways to increase (Fig. 3).

The results calculated for the diameters and the volumes are both highly significant ($p < 0.001$). Considering a confidence interval of 95% the results are approvingly accurate. No significant changes were found regarding time as well as no correlation was found between analysis and time. There are some relations between the three programs: the results of the comparison among them show statistically significant differences (Table 2).

**Table 1**
Measured distances (distance in millimetre, volume in cubic millimetre, mean ± standard deviation) using cephalometric analysis of the skull in 11 patients at three different times: shortly before surgery, within three months after surgery and after three months postoperative.

| Cephalometric and volumetric analysis of the PAS before and after Class III mandibular prognathism treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Unit (mm) | Mimics | | | OsiriX | | | BrainLab[a] & LCR | | |
| | T0 | T1 | T2 | T0 | T1 | T2 | T0 | T1 | T2 |
| Volume ($mm^3$) | $^{a}$ 16560.79 0 | $^{a}$ 20342.10 $^{A}$ | 18424.22 $^{A}$ | $^{a}$ 18757.270 | $^{a}$ 22699.70$^{A}$ | 20971.36$^{A}$ | $^{a}$ 19971.500 | $^{a}$ 24340.00$^{A}$ | 21630.22$^{A}$ |
| | $_{L}$ (11387.64) $_{\alpha}$ | $_{M}$ (13426.99) | $_{N}$ (8569.69) $_{\alpha}$ | $_{L+}$ (10875.23) $_{\alpha}$ | $_{M+}$ (12158.94) | $_{N+}$ (7912.65) $^{\alpha}$ | $^{a}_{L}$ (12327.59) $^{\alpha}$ | $^{a}_{M}$ (13457.84) | $^{a}_{N}$ (8757.65) $^{\alpha}$ |
| PNS-C | $^{a}$ 44.330 | $^{b}$ 49.68$^{A}$ | 48.01$^{A}$ | $^{a}$ 42.290 | $^{b}$ 48.20$^{A}$ | 46.00$^{A}$ | $^{a}$ 36.660 | $^{b}$ 41.30$^{A}$ | 40.06$^{A}$ |
| | $_{L+}$ (8.19) $_{\alpha}$ | $^{a}_{M+}$ (7.55) | $_{N}$ (6.99) $_{\beta}$ | $_{L+}$ (7.05) $_{\alpha}$ | $^{a}_{M}$ (7.38) | $_{N}$ (8.07) $^{\beta}$ | $_{L}$ (4.74) $^{\alpha}$ | $_{M+}$ (5.30) | $_{N}$ (5.27) $^{\alpha}$ |
| PNS-UPW | $^{a}$ 26.490 | $^{b}$ 30.69$^{A}$ | 30.28$^{A}$ | $^{a}$ 24.200 | $^{b}$ 29.39$^{A}$ | 27.94$^{A}$ | $^{a}$ 22.250 | $^{b}$ 25.81$^{A}$ | 25.64$^{A}$ |
| | $^{a}_{L+}$ (7.72) $_{\alpha}$ | $_{M}$ (7.09) | $^{a}_{N}$ (5.74) $_{\alpha}$ | $^{a}_{L}$ (5.80) $_{\alpha}$ | $_{M}$ (7.13) | $_{N+}$ (7.67) $^{\beta}$ | $_{L+}$ (2.96) $^{\alpha}$ | $_{M+}$ (4.25) | $^{a}_{N+}$ (4.45) $^{\alpha}$ |
| U-MPW | $^{a}$ 13.490 | $^{a}$ 13.98$^{A}$ | 14.85$^{A}$ | $^{a}$ 12.090 | $^{a}$ 12.76$^{A}$ | 13.48$^{A}$ | $^{a}$ 13.200 | $^{a}$ 13.69$^{A}$ | 15.09$^{A}$ |
| | $_{L}$ (3.92) $_{\alpha}$ | $_{M}$ (6.20) | $_{N}$ (4.12) $_{\alpha}$ | $_{L}$ (3.78) $_{\alpha}$ | $_{M}$ (6.27) | $_{N}$ (5.35) $^{\alpha}$ | $_{L}$ (3.78) $^{\alpha}$ | $_{M}$ (5.97) | $_{N}$ (3.36) $^{\alpha}$ |
| E-LPW | $^{a}$ 17.930 | $^{a}$ 17.17$^{A}$ | 17.90$^{A}$ | $^{a}$ 17.170 | $^{a}$ 16.72$^{A}$ | 17.13$^{A}$ | $^{a}$ 16.130 | $^{a}$ 16.09$^{A}$ | 15.00$^{A}$ |
| | $_{L}$ (4.19) $_{\alpha}$ | $_{M+}$ (5.22) | $_{N}$ (3.32) $_{\alpha}$ | $_{L}$ (5.26) $_{\alpha}$ | $^{a}_{M}$ (5.39) | $_{N}$ (3.21) $^{\alpha}$ | $_{L}$ (3.81) $^{\alpha}$ | $^{a}_{M+}$ (4.08) | $_{N}$ (5.31) $^{\alpha}$ |
| Pg-$PPW_2$ | $^{a}$ 82.550 | $^{a}$ 80.69$^{A}$ | 80.99$^{A}$ | $^{a}$ 83.230 | $^{a}$ 79.06$^{A}$ | 81.82$^{A}$ | $^{a}$ 78.890 | $^{a}$ 75.73$^{A}$ | 74.40$^{A}$ |
| | $_{L+}$ (10.48) $_{\alpha}$ | $_{M+}$ (8.37) | $_{N}$ (6.71) $_{\alpha}$ | $^{a}_{L}$ (10.62) $_{\alpha}$ | $^{a}_{M}$ (9.27) | $_{N}$ (7.17) $^{\alpha}$ | $^{a}_{L+}$ (11.63) $^{\alpha}$ | $^{a}_{M+}$ (14.57) | $_{N}$ (15.08) $^{\beta}$ |
| H-$PPW_1$ | $^{a}$ 31.070 | $^{a}$ 29.80$^{A}$ | 30.05$^{A}$ | $^{a}$ 30.600 | $^{a}$ 29.33$^{A}$ | 29.81$^{A}$ | $^{a}$ 30.800 | $^{a}$ 29.38$^{A}$ | 29.46$^{A}$ |
| | $_{L}$ (6.72) $_{\alpha}$ | $_{M}$ (5.78) | $_{N}$ (4.43) $_{\alpha}$ | $_{L}$ (5.79) $_{\alpha}$ | $_{M}$ (5.07) | $_{N}$ (3.73) $^{\alpha}$ | $_{L}$ (5.36) $^{\alpha}$ | $_{M}$ (5.64) | $_{N}$ (5.29) $^{\alpha}$ |
| $AP_{min}$ | $^{a}$ 9.930 | $^{a}$ 10.58$^{A}$ | 9.57$^{A}$ | $^{a}$ 9.39 | $^{a}$ 9.97$^{A}$ | 8.93$^{A}$ | $^{a}$ 9.850 | $^{a}$ 10.10$^{A}$ | 10.74$^{A}$ |
| | $_{L}$ (4.52) $_{\alpha}$ | $_{M}$ (5.88) | $_{N}$ (2.67) $_{\alpha}$ | $_{L}$ (4.07) $_{\alpha}$ | $_{M}$ (6.17) | $_{N}$ (3.54) $^{\alpha}$ | $_{L}$ (3.82) $^{\alpha}$ | $_{M}$ (4.08) | $_{N}$ (4.21) $^{\alpha}$ |

1. Within a software application, significant different values in the row between the groups 'T0' and 'T1' are marked with various lowercase letters (a < b).
2. Within a software application, significant different values in the row between the groups 'T1' and 'T2' are marked with various capital letters (A < B).
3. Within a software application, significant different values in the row between the groups 'T0' and 'T2' are marked with various Greek letters ($\alpha < \beta$).
4. Within a point of time (T0, T1, T2) in the row significant different values between the groups 'Mimics', 'OsiriX' and 'LCR' are marked with following capital letters: T0: L < L+ < L*, T1: M < M+ < M*, T2: N < N+ < N*.

[a] BrainLab software only used for volume measurement.

Please cite this article in press as: Burkhard JPM, et al., Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery, Journal of Cranio-Maxillo-Facial Surgery (2014), http://dx.doi.org/10.1016/j.jcms.2014.04.005

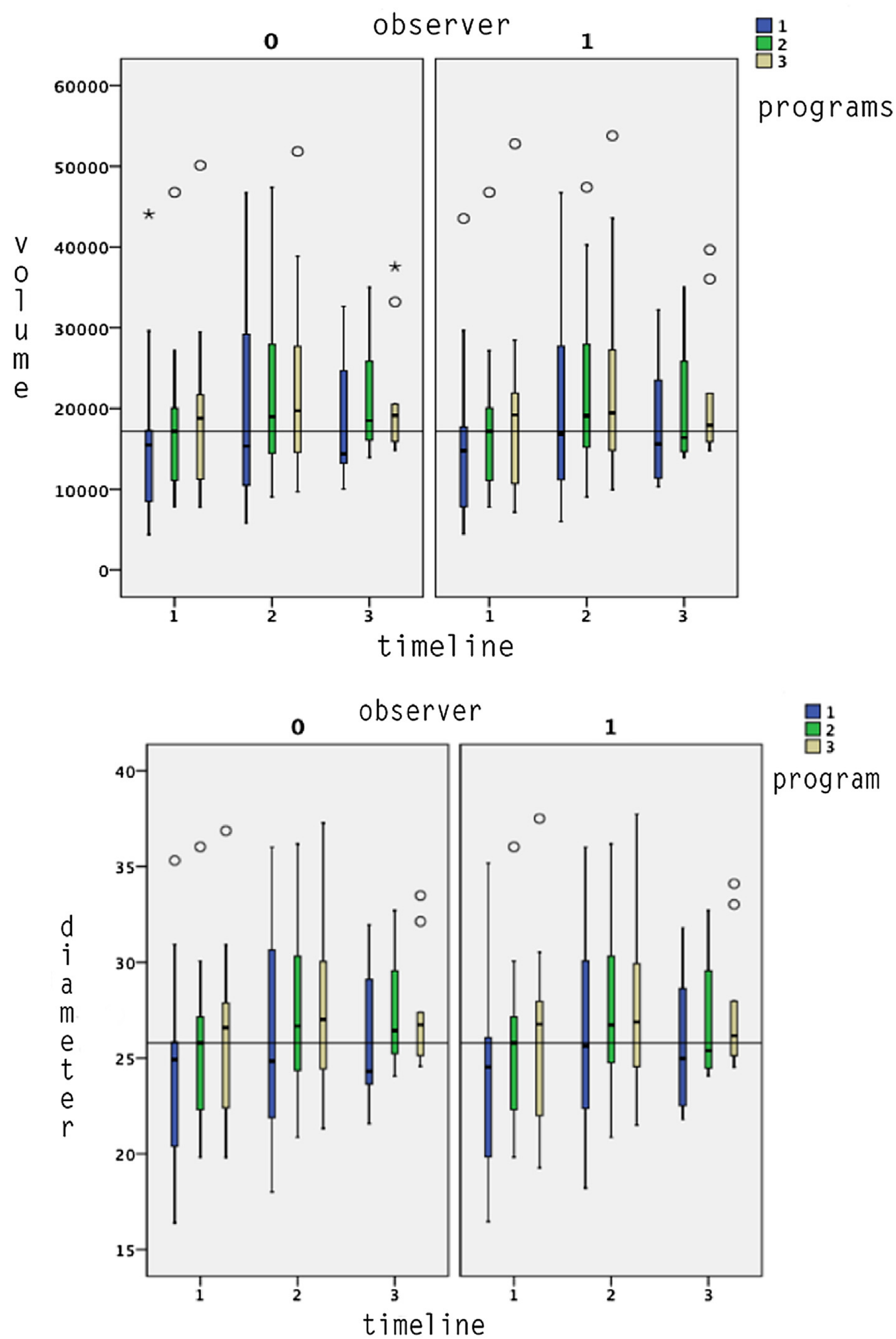


**Fig. 3.** Box-plots, calculation of diameter and volume at the times T0, T1, T2 from the two observers for the two imaging programs (Mimics = 1, OsiriX = 2) and the manual method (LCR = 3).

At the end, the reliability (part of variance which is not depending on the program) was calculated for diameter, volume, operators and programs. The results showed a very high reliability. Related to the diameter, the reliability revealed as 98.9% calculated between the two observers and 94.2% computed between the programs. Both results can be considered as exceptional. The reliability for the volume is even better, with a 99.2% for the observers and a 96.1% for the three programs.

The results of measuring the pharyngeal airway pre- and postoperatively revealed a significant increase of the upper airway shown by PNS-UPW alterations in cephalometric radiographs measured with Mimics®, OsiriX® and LCR after surgery (T0 to T1). As reference, a significant increase of PNS-C was measured after surgery (T1) in all programs. From T1 to T2 no significant changes were found for the distances PNS-C and PNS-UPW. Other mean values in the cephalometric analysis showed no statistically significant differences before and after surgery. Furthermore, it was shown that the lower jaw was slightly moved posteriorly. The hyoid bone position was unchanged. In the axial plane, no significant alterations were identified before and after surgical intervention. The three-dimensional analysis showed no significant changes in volume of the PAS pre- and postoperatively from T0 to T1 and T2

Please cite this article in press as: Burkhard JPM, et al., Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery, Journal of Cranio-Maxillo-Facial Surgery (2014), http://dx.doi.org/10.1016/j.jcms.2014.04.005

**Table 2**
Confidence interval. This post performed test shows p. e. the mean difference from program 1 (Mimics) to program 2 (OsiriX) and program 3 (LCR for diameter and BrainLab for volume) of −1.4 mm with a confidence interval going from lower bound −1.6 to upper bound −1.1.

| | Imaging program | | Mean difference | 95% Confidence interval | |
|---|---|---|---|---|---|
| | | | | Lower bound | Upper bound |
| Diameter | 1 | 2 | −1.3937* | −1.6421 | −1.1452 |
| | | 3 | −1.6990* | −1.9474 | −1.4505 |
| | 2 | 1 | 1.3937* | 1.1452 | 1.6421 |
| | | 3 | −.3053* | −.5538 | −.0568 |
| | 3 | 1 | 1.6990* | 1.4505 | 1.9474 |
| | | 2 | .3053* | .0568 | .5538 |
| Volume | 1 | 2 | −2355.461* | −2866.162 | −1844.760 |
| | | 3 | −3236.739* | −3747.440 | −2726.038 |
| | 2 | 1 | 2355.461* | 1844.760 | 2866.162 |
| | | 3 | −881.277* | −1391.979 | −370.576 |
| | 3 | 1 | 3236.739* | 2726.038 | 3747.440 |
| | | 2 | 881.277* | 370.576 | 1391.979 |

1. Positions marked with * characterize values where the mean difference is significant at 0, where the initial null hypothesis has been confirmed from Bonferroni's test.

after treatment. Nevertheless, an initial enlargement of the airway volume was observed at T1, which relapsed after a few months postoperatively (T2). For an $\alpha$-level of 0.016, no statistically significant values were found.

## 4. Discussion

### 4.1. Imaging software reliability

In this study 11 subjects were selected retrospectively from the database corresponding to specific requirements. Three commercially accessible software imaging programs that use (semi)-automatic segmentation to calculate airway volumes were tested (Mimics®, OsiriX®, BrainLab®). The linear measurement was examined with two different software programs and further manually with conventional LCR as a control measurement. For the manual method can be reported that there is a good reproducibility of single distances with all programs at all lengths. The higher statistically significance found for LCR may be attributed to the fact that the precision of the measurements may be impaired from the lightening conditions, fatigue, grey-scale ability, and visual acuity (Tiner et al., 1997). The fact that the operator has to define the segmentation levels, the beginning and the ending point of measured distances may also explain the statistically significant results found for Mimics® and OsiriX®.

The volume was calculated automatically in all three imaging programs. The third dimension can certainly improve the reliability of the results and obtain quantitative assessment of the airway. This study shows that the posterior airway volume measurement can be performed with all three different imaging programs. However, the interactive thresholding is based on the operators visual discrimination of the airway boundaries. Moreover the human vision is subjected to different factors. The operator subjectivity in boundary selection may be eliminated by using fixed thresholding (Guijarro-Martinez and Swennen, 2013).

Regarding the statistical evaluation of the volume, it may be concluded that the three investigated programs are significantly different from each other. Different factors may explain this finding. Influencing factors, such as i.e. the size of the selected volume or the removal of artefacts, should be taken in account. The change of the observer does not have any influence on the statistical significance, as the volumes were automatically measured (Schendel and Hatcher, 2010). Consequently, the selection of the upper and lower limit for the volume measurements does not seem to have influence on the outcome. Although, in the present study 11 subjects were examined, the good functionality of the programs could have been confirmed by the result of 96.1% of reliability.

According to the literature different research was conducted. A study that analyzed the accuracy and precision of imaging software programs by using a phantom as reference model discovered no significant differences between the airway measurement obtained with semi-augmented procedure and manual slice-by-slice technique using CT-scans (Schendel and Hatcher, 2010).

Recently, a systematic review on CBCT imaging and analysis of the upper airway was performed, proving the accuracy and reliability of this 3D imaging tools and discussing the obstacles whom still need to be addressed (Guijarro-Martinez and Swennen, 2011). Difficulties for the analysis can be the impact of the respiration phase, the influence of the tongue position and mandible morphology. Another study compared the precision and accuracy of 6 imaging software programs (including OsiriX® and Mimics®) measuring the upper airway volumes in CBCT. Taking a known oropharynx acrylic phantom volume as standard, 33 patients were analyzed with semiautomatic segmentations with interactive and fixed threshold protocols. The reliability for all 6 programs was high, which matches to the findings in this study. Only four of the analyzed studies (working with Mimics® and OsiriX®) were significantly different and only two of them showed no statistical difference (Weissheimer et al., 2012). El and Palomo analyzed three different imaging software programs and showed a high reliability for all investigated programs. The results were comparable to those of the present study (El and Palomo, 2010).

In scope of this study the two-dimensional and three-dimensional analysis in all three investigated programs showed a high reliability at all lengths and volumes. The reliability is higher compared with digital imaging programs than with manual measurement technique. Software based calculation of the dimensions of the pharyngeal airway should be preferred.

### 4.2. Pre- and postoperative changes in pharyngeal airway dimension

Most studies in the past were mainly examining morphologic changes of the posterior airway space with or without additional surgical procedures by using traditional cephalometric radiographs. The present study faces the differences of alterations of the pharyngeal airway dimensions before and after surgery between linear (LCR) and digital volume calculation. In all cases, the mandible was set backwards by simultaneous forward movement of the maxilla by using Le Fort I osteotomy to preserve nasal breathing and carry out an improvement of the facial profile.

Because of adaptive changes in soft and hard tissues after surgical intervention, all subjects were examined at two different times (T1 and T2) postoperatively (Wickwire et al., 1972). The short term of three-months interval (T1) was chosen in order to avoid impreciseness concerning the postsurgical tissue swelling as well as irritation of the tongue, uvula and hypopharynx that may occur proximately after surgery.

A significant increase of the upper airway was found after surgery by PNS-UPW alterations in cephalometric radiographs. As well the distance PNS-C increased significantly after surgery corresponding to the forward movement of the maxilla. A slight, but not statistically significant increase in the U-MPW level was detected in short (T1) and long-term (T2) in lateral head films. Only a minimal shortening at the E-LPW level was observed that implicate that the negative effects after mandibular setback on the lower part of the airway might be reduced by maxillomandibular surgery. Other mean values in the cephalometric analysis showed no statistically significant differences before and after surgery. Moreover, it was shown that the lower jaw was slightly moved posteriorly and the hyoid bone position remained unchanged.

The results of the present study seem to confirm that maxillary advancement surgery can prevent the narrowing of the upper airway in the correction of Class III deformities in comparison with mandibular setback surgery (Chen et al., 2007; Degerliyurt et al., 2008). It is known that single maxillary advancement leads to an enlargement of the nasopharyngeal space and the oropharyngeal area (Frohberg and Greco, 1990). Conversely, mandibular setback surgery may reduce the pharyngeal airway size and can contribute to a postoperative development of OSA symptoms (Hochban et al., 1997; Eggensperger et al., 2005; Kawakami et al., 2005). In order to secure the airway, a simultaneous forward movement of the maxilla can be performed. Because the maxilla is postoperatively located more anteriorly, the tongue undergoes a slight adapted adequate anterior motion to ensure speech articulation, chewing and swallowing (Frohberg and Greco, 1990).

According to three-dimensional evaluation of the PAS slight – but not statistically significant – changes were observed in volume alterations of the pharyngeal dimensions before (T0) and after surgery (T1 and T2). An initial enlargement of the airway volume was observed at T1, which decreased after a few months postoperatively (T2). These findings are consistent with recent study results. However, the reduction was more marked in those who underwent mandibular setback only (Degerliyurt et al., 2008). One reason could be the amount of mandibular setback to be less by simultaneous advancement of the maxilla than in single mandibular setback surgery. Another explication may be the prevention of narrowing the upper pharyngeal airway by maxillary forward movement (Marsan et al., 2009). Other reports observed also significant changes in pharyngeal airway volume after maxillomandibular surgery in Class III patients of short and long terms with a continuous decrease of the pharyngeal airway dimensions correlated with an inferior posterior downward movement of the hyoid bone (Park et al., 2012; Kim et al., 2013a,b).

In the present study, the hyoid bone had no significant change in position at any time (T0, T1 and T2). In literature, there are many different results of hyoid bone movements. Some authors are proposing an inferior (Achilleos et al., 2000; Samman et al., 2002), an inferior and posterior (Lew, 1993; Eggensperger et al., 2005; Guven and Saracoglu, 2005), or an inferior and forward movement (Lew, 1993; Achilleos et al., 2000; Tselnik and Pogrel, 2000; Kawakami et al., 2005). Similarly, concerning the postoperative stability of the hyoid bone position, various opinions are postulated. Some investigators suggest that changes after mandibular setback are a temporary phenomenon with a return to almost the original preoperative position (Athanasiou et al., 1991; Samman et al., 2002). Other authors claimed that the hyoid bone might never regain its original position (Achilleos et al., 2000; Tselnik and Pogrel, 2000; Eggensperger et al., 2005).

Comparisons of volume renderings with lateral head film measurements are rarely discussed. This study confirms that the comparability of linear and volumetric measurement of the pharyngeal airway space is limited. Although a linear increase in size of the measured upper respiratory tract could be demonstrated from T0 to T1 (PNS-UPW, U-MPW, minimal E-LPW), the axial plane showed no changes and the volume of the pharyngeal airway showed no significant alterations neither short nor long-term. Shaw et al. attempted to determine if two-dimensional measurements from conventional cephalometric lateral skull radiographs are comparable to those derived from three-dimensional CBCT images. They found that measurements used in the Eastman cephalometric analysis that originated from two-dimensional cephalometric lateral skull images are comparable to those resulting from three-dimensional CBCT images (Shaw et al., 2013). A cephalometric and three-dimensional assessment study of the posterior airway space after maxillomandibular advancement showed significant increase in linear area and volume measurement. After 6 months, the pharyngeal airway dimensions became narrower compared with the immediate postoperative period. The authors confirmed that the linear analysis of airway space has limited results when compared to an analysis of area and volume (de Souza Carvalho et al., 2012).

The comparison of current literature is challenging. Many different results were described in the past few years measuring the pharyngeal airway dimension with different methods (Athanasiou et al., 1991; Lee et al., 2012; Kim et al., 2013a,b). Scant attention has been applied to the reasons for such a discrepancy in results. Certainly, a reason for this diversity of results might be the variety of surgical techniques and their non-standardized implementation in former studies. But in the broader sense, the evaluation of CBCT-scans and cephalometric radiographs especially need certain standards in image recording techniques to be coherent. While cephalometric radiographs and CBCT-scans are usually carried out with the patient in a standing or sitting upright position, CT- or MRT-scans require the patient to be supine. The gravitational effect in response to postural changes caused significant changes in the position of oropharyngeal structures, wherein differences can occur in standing or sitting positions as well (Sutthiprapaporn et al., 2008). Subsequently, upright positioning may have certain advantages by preserving volume and contours of the upper airway space (Pae et al., 1994). Furthermore, when measuring the pharyngeal airway dimensions it is important to consider how changes in head posture affect the size of the pharyngeal airway (Hellsing, 1989; Kim et al., 2013a,b). Natural head posture varies among individuals when taking radiographs as well as in physiologic posture at different points in time (Cole, 1988; Muto et al. 2002). Many studies showed an increase of distances and volume of the pharyngeal airway space by head extension, especially at the uppermost part of the cervical spine. The distance from the hyoid bone to the mandible is also affected by head posture (Muto et al., 2006). Both patient positioning and respiration phase during imaging procedures have significant influence on the upper airway dimensions (Muto et al., 2002).

However, the quality of the radiograph did affect identification of the horizontal position of the hyoid bone and the linear measurement of posterior airway space, although these were not clinically significant. The vertical position of the tip of the soft palate was highly unreliable, irrespective of the quality of the radiograph. This resulted in errors in the measurement of the soft palate length. Future airway-related research should consider the potential inaccuracies when attempting to identify these dynamic three-dimensional structures on static two-dimensional images. All of these factors are supplementary contributions to the high variability of the results.

The large variability in study designs in terms of surgical methods, imaging techniques, defined landmarks on radiographs, different uses of software programs, patient conditions, and many other factors aggravate a comparison and a clear meaning of all linear and volumetric pharyngeal airway space measurement results. Therefore, it is important to use uniform examiner criteria for future research because measuring the pharyngeal airway dimensions using CBCT will be continuously important in planning and follow-up of surgical treatment for mandibular prognathism and in the diagnosis of obstructive sleep apnoea.

## 5. Conclusion

The present study confirms that a three-dimensional design of the posterior airway seems to be far more reliable and precise phrasing of a statement of postoperative gradients than conventional radiography and is additionally higher compared to the corresponding manual method. In case of Class III mandibular prognathism treatment with bilateral split osteotomy of the mandible and simultaneous maxillary advancement, the negative effects of PAS volume decrease may be reduced and might prevent a developing OSAS.

## Conflict of interest

None of the authors have conflicts of interest or personal or financial relationships with other people or organizations within this study.

## References


Aboudara C, Nielsen I, Huang JC, Maki K, Miller AJ, Hatcher D: Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography. Am J Orthod Dentofacial Orthop 135(4): 468–479, 2009

Abramson ZR, Susarla S, Tagoni JR, Kaban L: Three-dimensional computed tomographic analysis of airway anatomy. J Oral Maxillofac Surg 68(2): 363–371, 2010

Achilleos S, Krogstad O, Lyberg T: Surgical mandibular setback and changes in uvuloglossopharyngeal morphology and head posture: a short- and long-term cephalometric study in males. Eur J Orthod 22(4): 383–394, 2000

Angelopoulos C: Cone beam tomographic imaging anatomy of the maxillofacial region. Dent Clin North Am 52(4): 731–752, 2008 vi

Athanasiou AE, Toutountzakis N, Mavreas D, Ritzau M, Wenzel A: Alterations of hyoid bone position and pharyngeal depth and their relationship after surgical correction of mandibular prognathism. Am J Orthod Dentofacial Orthop 100(3): 259–265, 1991

Celenk M, Farrell ML, Eren H, Kumar K, Singh GD, Lozanoff S: Upper airway detection and visualization from cone beam image slices. J Xray Sci Technol 18(2): 121–135, 2010

Chen F, Terada K, Hua Y, Saito I: Effects of bimaxillary surgery and mandibular setback surgery on pharyngeal airway measurements in patients with Class III skeletal deformities. Am J Orthod Dentofacial Orthop 131(3): 372–377, 2007

Cole SC: Natural head position, posture, and prognathism: the Chapman Prize Essay, 1986. Br J Orthod 15(4): 227–239, 1988

de Souza Carvalho AC, Magro Filho O, Garcia IR, Araujo PM, Nogueira RL: Cephalometric and three-dimensional assessment of superior posterior airway space after maxillomandibular advancement. Int J Oral Maxillofac Surg 41(9): 1102–1111, 2012

Degerliyurt K, Ueki K, Hashiba Y, Marukawa K, Nakagawa K, Yamamoto E: A comparative CT evaluation of pharyngeal airway changes in class III patients receiving bimaxillary surgery or mandibular setback surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 105(4): 495–502, 2008

Eggensperger N, Smolka W, Iizuka T: Long-term changes of hyoid bone position and pharyngeal airway size following mandibular setback by sagittal split ramus osteotomy. J Craniomaxillofac Surg 33(2): 111–117, 2005

El H, Palomo JM: Measuring the airway in 3 dimensions: a reliability and accuracy study. Am J Orthod Dentofacial Orthop 137(4 Suppl.): S50.e51–S50.e59, 2010 discussion S50–S52

Fairburn SC, Waite PD, Vilos G, Harding SM, Bernreuter W, Cure J, et al: Three-dimensional changes in upper airways of patients with obstructive sleep apnea following maxillomandibular advancement. J Oral Maxillofac Surg 65(1): 6–12, 2007

Frohberg U, Greco JM: Maxillary osteotomy: an alternative treatment concept for obstructive sleep apnea syndrome. Dtsch Z Mund Kiefer Gesichtschir 14(5): 343–347, 1990

Goncalves JR, Buschang PH, Goncalves DG, Wolford LM: Postsurgical stability of oropharyngeal airway changes following counter-clockwise maxillo-mandibular advancement surgery. J Oral Maxillofac Surg 64(5): 755–762, 2006

Grauer D, Cevidanes LS, Proffit WR: Working with DICOM craniofacial images. Am J Orthod Dentofacial Orthop 136(3): 460–470, 2009

Grimm W, Becker HF: Obesity, sleep apnea syndrome, and rhythmogenic risk. Herz 31(3): 213–218, 2006 quiz 219

Guijarro-Martinez R, Swennen GR: Cone-beam computerized tomography imaging and analysis of the upper airway: a systematic review of the literature. Int J Oral Maxillofac Surg 40(11): 1227–1237, 2011

Guijarro-Martinez R, Swennen GR: Three-dimensional cone beam computed tomography definition of the anatomical subregions of the upper airway: a validation study. Int J Oral Maxillofac Surg 42(9): 1140–1149, 2013

Guldner C, Diogo I, Windfuhr J, Bien S, Teymoortash A, Werner JA, et al: Analysis of the fossa olfactoria using cone beam tomography (CBT). Acta Otolaryngol 131(1): 72–78, 2011

Guven O, Saracoglu U: Changes in pharyngeal airway space and hyoid bone positions after body ostectomies and sagittal split ramus osteotomies. J Craniofac Surg 16(1): 23–30, 2005

Hellsing E: Changes in the pharyngeal airway in relation to extension of the head. Eur J Orthod 11(4): 359–365, 1989

Hernandez-Alfaro F, Guijarro-Martinez R, Mareque-Bueno J: Effect of mono- and bimaxillary advancement on pharyngeal airway volume: cone-beam computed tomography evaluation. J Oral Maxillofac Surg 69(11): e395–400, 2011

Hochban W, Conradt R, Brandenburg U, Heitmann J, Peter JH: Surgical maxillofacial treatment of obstructive sleep apnea. Plast Reconstr Surg 99(3): 619–626, 1997 discussion 627–618

Hong JS, Park YH, Kim YJ, Hong SM, Oh KM: Three-dimensional changes in pharyngeal airway in skeletal class III patients undergoing orthognathic surgery. J Oral Maxillofac Surg 69(11): e401–408, 2011

Jakobsone G, Neimane L, Krumina G: Two- and three-dimensional evaluation of the upper airway after bimaxillary correction of Class III malocclusion. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 110(2): 234–242, 2010

Kawakami M, Yamamoto K, Fujimoto M, Ohgi K, Inoue M, Kirita T: Changes in tongue and hyoid positions, and posterior airway space following mandibular setback surgery. J Craniomaxillofac Surg 33(2): 107–110, 2005

Kim MA, Kim BR, Choi JY, Youn JK, Kim YJ, Park YH: Three-dimensional changes of the hyoid bone and airway volumes related to its relationship with horizontal anatomic planes after bimaxillary surgery in skeletal Class III patients. Angle Orthod 83(4): 623–629, Jul. 2013a

Kim MA, Kim BR, Youn JK, Kim YJ, Park YH: Head posture and pharyngeal airway volume changes after bimaxillary surgery for mandibular prognathism. J Craniomaxillofac Surg, 2013b. pii: S1010-5182(13)00220-5

Lee Y, Chun YS, Kang N, Kim M: Volumetric changes in the upper airway after bimaxillary surgery for skeletal class III malocclusions: a case series study using 3-dimensional cone-beam computed tomography. J Oral Maxillofac Surg 70(12): 2867–2875, 2012

Lenza MG, Lenza MM, Dalstra M, Melsen B, Cattaneo PM: An analysis of different approaches to the assessment of upper airway morphology: a CBCT study. Orthod Craniofac Res 13(2): 96–105, 2010

Lew KK: Changes in tongue and hyoid bone positions following anterior mandibular subapical osteotomy in patients with Class III malocclusion. Int J Adult Orthodon Orthognath Surg 8(2): 123–128, 1993

Li KK, Riley RW, Powell NB, Guilleminault C: Patient's perception of the facial appearance after maxillomandibular advancement for obstructive sleep apnea syndrome. J Oral Maxillofac Surg 59(4): 377–380, 2001 discussion 380–371

Li KK, Riley RW, Powell NB, Troell R, Guilleminault C: Overview of phase II surgery for obstructive sleep apnea syndrome. Ear Nose Throat J 78(11), 1999 851, 854–857

Lye KW: Effect of orthognathic surgery on the posterior airway space (PAS). Ann Acad Med Singapore 37(8): 677–682, 2008

Mah JK, Danforth RA, Bumann A, Hatcher D: Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 96(4): 508–513, 2003

Marsan G, Oztas E, Cura N, Kuvat SV, Emekli U: Changes in head posture and hyoid bone position in Turkish Class III patients after mandibular setback surgery. J Craniomaxillofac Surg 38(2): 113–121, 2010

Marsan G, Vasfi Kuvat S, Oztas E, Cura N, Susal Z, Emekli U: Oropharyngeal airway changes following bimaxillary surgery in Class III female adults. J Craniomaxillofac Surg 37(2): 69–73, 2009

Mehra P, Downie M, Pita MC, Wolford LM: Pharyngeal airway space changes after counterclockwise rotation of the maxillomandibular complex. Am J Orthod Dentofacial Orthop 120(2): 154–159, 2001

Muto T, Takeda S, Kanazawa M, Yamazaki A, Fujiwara Y, Mizoguchi I: The effect of head posture on the pharyngeal airway space (PAS). Int J Oral Maxillofac Surg 31(6): 579–583, 2002

Muto T, Yamazaki A, Takeda S: A cephalometric evaluation of the pharyngeal airway space in patients with mandibular retrognathia and prognathia, and normal subjects. Int J Oral Maxillofac Surg 37(3): 228–231, 2008

Muto T, Yamazaki A, Takeda S, Kawakami J, Tsuji Y, Shibata T, et al: Relationship between the pharyngeal airway space and craniofacial morphology, taking into account head posture. Int J Oral Maxillofac Surg 35(2): 132–136, 2006


Please cite this article in press as: Burkhard JPM, et al., Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery, Journal of Cranio-Maxillo-Facial Surgery (2014), http://dx.doi.org/10.1016/j.jcms.2014.04.005

Pae EK, Lowe AA, Sasaki K, Price C, Tsuchiya M, Fleetham JA: A cephalometric and electromyographic study of upper airway structures in the upright and supine positions. Am J Orthod Dentofacial Orthop 106(1): 52–59, 1994
Park SB, Kim YI, Son WS, Hwang DS, Cho BH: Cone-beam computed tomography evaluation of short- and long-term airway change and stability after orthognathic surgery in patients with Class III skeletal deformities: bimaxillary surgery and mandibular setback surgery. Int J Oral Maxillofac Surg 41(1): 87–93, 2012
Popat H, Richmond S, Marshall D, Rosin PL: Three-dimensional assessment of functional change following Class 3 orthognathic correction – a preliminary report. J Craniomaxillofac Surg 40(1): 36–42, 2012
Prinsell JR: Maxillomandibular advancement surgery for obstructive sleep apnea syndrome. J Am Dent Assoc 133(11): 1489–1497, 2002 quiz 1539–1440
Riley RW, Powell NB, Guilleminault C: Current surgical concepts for treating obstructive sleep apnea syndrome. J Oral Maxillofac Surg 45(2): 149–157, 1987
Riley RW, Powell NB, Guilleminault C: Maxillary, mandibular, and hyoid advancement for treatment of obstructive sleep apnea: a review of 40 patients. J Oral Maxillofac Surg 48(1): 20–26, 1990
Rustemeyer J, Gregersen J: Quality of life in orthognathic surgery patients: post-surgical improvements in aesthetics and self-confidence. J Craniomaxillofac Surg 40(5): 400–404, 2012
Samman N, Tang SS, Xia J: Cephalometric study of the upper airway in surgically corrected class III skeletal deformity. Int J Adult Orthodon Orthognath Surg 17(3): 180–190, 2002
Schendel SA, Epker BN: Results after mandibular advancement surgery: an analysis of 87 cases. J Oral Surg 38(4): 265–282, 1980
Schendel SA, Hatcher D: Automated 3-dimensional airway analysis from cone-beam computed tomography data. J Oral Maxillofac Surg 68(3): 696–701, 2010
Shaw K, McIntyre G, Mossey P, Menhinick A, Thomson D: Validation of conventional 2D lateral cephalometry using 3D cone beam CT. J Orthod 40(1): 22–28, 2013
Sutthiprapaporn P, Tanimoto K, Ohtsuka M, Nagasaki T, Iida Y, Katsumata A: Positional changes of oropharyngeal structures due to gravity in the upright and supine positions. Dentomaxillofac Radiol 37(3): 130–135, 2008
Tiner BD: Surgical management of obstructive sleep apnea. J Oral Maxillofac Surg 54(9): 1109–1114, 1996
Tiner BD, Van Sickels JE, Schmitz JP: Life-threatening, delayed hemorrhage after Le Fort I osteotomy requiring surgical intervention: report of two cases. J Oral Maxillofac Surg 55(1): 91–93, 1997 discussion 93–94
Tselnik M, Pogrel MA: Assessment of the pharyngeal airway space after mandibular setback surgery. J Oral Maxillofac Surg 58(3): 282–285, 2000 discussion 285–287
Turnbull NR, Battagel JM: The effects of orthognathic surgery on pharyngeal airway dimensions and quality of sleep. J Orthod 27(3): 235–247, 2000
Weissheimer A, Menezes LM, Sameshima GT, Enciso R, Pham J, Grauer D: Imaging software accuracy for 3-dimensional analysis of the upper airway. Am J Orthod Dentofacial Orthop 142(6): 801–813, 2012
Wickwire NA, White Jr RP, Proffit WR: The effect of mandibular osteotomy on tongue position. J Oral Surg 30(3): 184–190, 1972

Please cite this article in press as: Burkhard JPM, et al., Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery, Journal of Cranio-Maxillo-Facial Surgery (2014), http://dx.doi.org/10.1016/j.jcms.2014.04.005

## Begleittext zur Publikation (equal contribution)

### Fragestellung

Das Ziel dieser Studie war es, einerseits die Präzision und Genauigkeit von drei verschiedenen Software Programmen (*OsiriX* 64-bit®, Open-Source Software; *Mimics*, Materialise HQ, Leuven Belgium; *BrainLab*®, BrainLab AG, Feldkirchen, Germany) zu testen, andererseits die morphologischen Veränderungen der oropharyngealen Strukturen und der hinteren Atemwege (posterior airway space - PAS) bei Patienten mit mandibulärer Prognathie und Retromaxillie vor und nach chirurgischem Eingriff mit 2D und 3D Verfahren zu berechnen.

### Material und Methoden

*Studiendesign*

In dieser Studie wurden 11 Patienten, die sich einer maxillomandibulären Behandlung zur Korrektur einer Klasse 3 Malokklusion unterzogen haben, durch Ausschlusskriterien ausgewählt (3 männliche und 8 weibliche zwischen 16 und 43 Jahren) und untersucht. Standardisierte konventionelle Fernröntgen und digitale Volumentomogramme (DVT) wurden bei jedem Individuum präoperativ (T0), 3 Monate postoperativ (T1) und ab 3 Monaten bis zu 2 Jahren (T2) angefertigt. Der chirurgische Eingriff erfolgte in allen Fällen gleich mit einer Le Fort 1 Osteotomie und gleichzeitiger sagittaler Spaltung des Unterkiefers. Veränderungen des pharyngealen Volumens und der Strecken des PAS wurden durch zwei verschiedene Untersucher mit drei verschiedenen Software-Programmen und manuell mit Fernröntgen eruiert.

*Bildgebung und Bildverarbeitung*

Für die 2D Analyse wurde jedes konventionelle Fernröntgenbild manuell bearbeitet und zudem wurden DVT-Schnittbilder mit einer Schnittebene auf Höhe der Sella turcica softwaregestützt (mit OsiriX® und Mimics®) ausgewertet. Analoge Fernröntgen wurden von Hand durchgezeichnet und als Kontrolle verwendet.
Für die 3D Analyse wurden die Volumen mit den Programmen OsiriX®, Mimics® und BrainLab® berechnet.

*Referenzpunkte*

Die Referenzpunkte wurden wie folgt ausgewählt: die Schädelbasis wurde von der Mitte der Sella turcica (S) bis zum vordersten Punkt der nasofrontalen Sutur (N) festgelegt und als Referenzstruktur benutzt. Eine senkrecht gezogene Linie durch S wurde als vertikale Referenzlinie (VR) benutzt, um alle zephalometrisch vertikalen Abstände zu dieser Linie zu messen. Eine Linie, die die Schädelbasis (C) mit der Spina nasalis posterior (PNS) verbindet, bestimmt den oberen Rand des PAS. Die pharyngeale Hinterwand dient als hintere Begrenzung, hingegen dienen der Zungengrund, der weiche Gaumen und die Uvula als vordere Begrenzung. Die anteroposteriore pharyngeale Dimension wurde in drei verschiedenen Ebenen vertikal zu VR gemessen.

Die obere anteroposteriore PAS Strecke (UPW) wurde begrenzt durch die Verbindung von der Spina nasalis posterior (PNS) und der pharyngealen Hinterwand. Die mittlere PAS Strecke (MPW) wurde gemessen vom hintersten Punkt der Zunge zur Pharynxhinterwand. Die untere PAS Strecke (LPW) wurde begrenzt durch eine Linie, die die Basis der Epiglottis (E) mit der pharyngealen Hinterwand verbindet. $AP_{min}$ ist hingegen definiert als die kürzeste Strecke des PAS.

Um die Position des Hyoidknochens und der Mandibula festzulegen, wurden zwei parallele Linien von der hinteren Pharynxwand zum vorderen Teil des Hyoidknochens (H) und dem vordersten Punkt des Kinns (Pg) gezogen.

*Statistik*

Die erhaltenen Daten wurden mit Microsoft® Excel® (Version 2011 für Macintosh) bearbeitet und statistisch mit Statistical Package for Social Sciences for Mac (SPSS Version 20, Chicago) analysiert. Die Reproduzierbarkeit zwischen den zwei Untersuchern wurde mittels Dahlberg Formel errechnet. Das Ergebnis des Vergleichs der verschiedenen Programme in Bezug auf 2D und 3D Analysen wurde mit dem nicht-parametrischen Wilcoxon Test erarbeitet. Für die 3D Analyse wurden der Durchmesser und das Volumen benutzt, der Durchmesser war notwendig, um die Normalverteilung darzustellen. Es wurde ein Konfidenzintervall von 95% gewählt und die Verlässlichkeit der Programme berechnet.

**Resultate**

Die Analyse von den drei verschiedenen Softwareprogrammen zeigt bei der gemessenen Strecke PNS-C zum Zeitpunkt T0 einen statistisch signifikanten Unterschied ($p < 0.05$) zwischen Handmessung (FRS) und Softwaremessung (OsiriX® und Mimics®). Auch ist der Unterschied der Längen PNS-UPW statistisch signifikant zum Zeitpunkt T0 zwischen OsiriX® und FRS. Das gleiche Resultat findet man auch zum Zeitpunkt T1, wo noch signifikante Unterschiede für die Strecke PNS-UPW im FRS zu Mimics gefunden werden. Es gibt weitere kleine signifikante Unterschiede der Strecken zwischen den verschiedenen Programmen zu den untersuchten Zeitpunkten. Generell geben die Resultate keinen statistisch geprüften Unterschied für eine einzelne Streckenmessung was als Zufallsfaktor gilt.

Die Patienten hatten grosse Unterschiede des Volumens bei jeder Messung. Alle Softwareprogramme zeigen die gleiche Entwicklung des Volumens zu den verschiedenen Zeitpunkten.

Die ausgerechneten Resultate für Durchmesser und Volumen sind beide hoch signifikant ($p < 0.001$). Wenn man bedenkt, dass als Konfidenzintervall 95% gewählt wurde, sind die Resultate sehr genau. Die Verlässlichkeit ausgerechnet mit dem Durchmesser ist 98.9% in Bezug auf die zwei Untersucher, und 94.2% für die Programme. Respektive haben wir für das Volumen die Werte von 99.2% und 96.1% erhalten, was noch besser ist.

Von präoperativ T0 zu postoperativ T1 findet eine Vergrösserung der PAS Strecken statt, eine Tendenz, die man bei den meisten Messpunkten wiederfindet, besonders im oberen Pharyngealraum. Von T1 zu T2 findet man keine grossen Veränderungen.

Der Unterkiefer befand sich nach Chirurgie leicht nach hinten versetzt, wohingegen die Position des Hyoidknochens unverändert blieb.

Die 3D Analyse zeigt keine signifikanten Unterschiede zu den Zeitpunkten T0, T1, T2. Trotzdem kann man zum Zeitpunkt T1 eine kleine anfängliche Vergrösserung des Volumens verzeichnen, die nach ein paar Monaten aber wieder zurückgeht (zum Zeitpunkt T2).

**Konklusion**

Diese Studie bestätigt, was auch schon in anderen Studien gezeigt wurde, dass die 3D Verfahren zur Messung des PAS zuverlässiger und genauer als die 2D Verfahren sind. Man sollte diese bevorzugen, da es eine sichere und einfache Technik ist, um quantitative Werte der Atemwege zu erhalten.
Dank des chirurgischen Verfahrens der Repositionierung des Unterkiefers mit simultaner bilateraler Split-Osteotomie des Oberkiefers bei Klasse 3 Malokklusionen kann man vielleicht die negativen Effekte auf die Atemwege korrigieren und eventuell ein OSAS vermeiden.

**Eigener Beitrag zur Forschungsarbeit**

Unter mehr als 300 Patienten wurden durch genaue Einschlusskriterien schlussendlich elf Patienten für diese Studie ausgewählt. Die Patienten wurden retrospektiv durch Prüfung der Krankenakten am Universitätsspital Zürich rekrutiert. Es wurden sowohl bestehende konventionelle Fernröntgen von Hand vermessen, sowie DICOM-Files mittels drei verschiedenen Softwareprogrammen (OsiriX®, Mimics®, BrainLab®) ausgemessen.
Die statistische Auswertung erfolgte mittels SPSS for Mac Version 20 unter Verwendung von nicht parametrischen Tests. Die Datenauswertung wurde statistisch in einer Tabelle festgehalten.
Meine Aufgabe bestand darin, die für die Studie geeigneten Patienten zu suchen. Dazu waren Röntgenbilder nötig, auf denen alle für die Messungen notwendigen Strukturen gut sichtbar waren. Patienten, bei denen auch alle 3 Röntgenbilder (zu den Zeitpunkten T0, T1, T2) vorhanden waren, mussten eingegliedert und entweder von Hand oder softwaregestützt vermessen und ausgewertet werden. Die digitale Bearbeitung der DICOM-Files habe ich jeweils in 2-dimensional und 3-dimensional mit entsprechenden Software Applikationen durchgeführt. Die statistische Auswertung zur Vergleichbarkeit der Präzision der drei Softwareprogramme habe ich mit SPSS® getätigt, in Tabelle 2 veranschaulicht und mit derzeitiger Literatur diskutiert.